A First Year Progress Report on "Collaborative Research: Using Low Cost Desktop Learning Modules to Educate Diverse Undergraduate Communities in Engineering"

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Biosketch

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Aminul Islam Khan is committed to excellence in teaching as well as research and always promotes a student-centered learning environment. He has a keen ability to teach, advise, and recruit students. He has proven himself to be a very effective researcher by publishing several journal articles. His resume has a substantial list of publications, including peer-reviewed articles in national and international journals and conferences. Moreover, he has joined in several reputed conferences, for example American Physical Society (APS), and presented his scholarly works.

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Abstract:

Hands-on activities can be used in engineering classrooms to bolster student participation and understanding of concepts. Often, financial burdens and the time necessary to design, modify, and create these activities can inhibit widespread use. To address these common barriers, we have designed low-cost desktop learning modules (LC-DLMs) that are less than the cost of a textbook, established a dissemination plan to propagate their use across the nation, and developed robust measures to assess the effectiveness of both the LC-DLMs and dissemination efforts. We hypothesize that updates to the physical modules and accompanying materials will improve students' conceptual understanding and that a systematic propagation, along with faculty support, will see increased use of these hands-on modules.

During the past year, we have made progress in each of the three objectives of this NSF project. To propagate use of LC-DLMs, we have continued our hub-and-spoke dissemination plan. Workshops were scheduled for two of the seven national hubs that serve as locations for one-time training workshops for geographically close "spoke" participants, specifically the Southeast and Central Hubs. Due to weather, the workshops were consolidated. At the workshop, participants heard presentations on the motivation behind this project, DLM design, instructional philosophy, and best implementation practices, and also had a chance to use all four modules in conjunction with suggested classroom worksheets.

The effectiveness of the LC-DLMs has been previously tested; however, there was a lack of robust measures for assessing student understanding in prior implementations of LC-DLMs. To address this, we used Bloom's taxonomy to categorize learning outcomes, measure learning gains, and better analyze understanding of concepts embedded in use of exercises that involve the LC-DLMs. Faculty from the currently participating institutions, administer the same cognitive pre- and posttests, as well as a motivational survey. Preliminary data shows that certain modules increase student understanding for the hydraulic loss module, while additional modifications need to be made to the double pipe heat exchanger activity to enhance the student experience.

Additional participants will be added in Fall 2020 and we anticipate that all four modules will be available for faculty at that time. We will continue to collect data in support of our hypothesis that these hands-on learning modules will enhance student learning.

Introduction:

With the increasing complexity of our world and the problems we face, there is a need for engineers to approach such issues with an eye for innovation. To reach that level of skill, however, there must be a strong foundation of fundamental concepts. As educators, if we expect students to become the future innovators of society, we ourselves must also use innovative approaches to teach. Alternative and complementary learning methods have been explored within engineering education for the past several decades to enhance the learning experience and aid in student comprehension. Although collaborative learning approaches such as think-pair-share are commonly used and have proven to be effective [1], hands-on learning has increased in popularity due to the potential for being more applicable to engineering students and similar to projects or equipment they will work on in industry.

To increase accessibility to hands-on learning in engineering, Low Cost Desktop Learning Modules (LC-DLMs) were created by the Van Wie group at Washington State University. LC-DLMs are hands-on apparatuses in which activities associated with them may be used to supplement lecture material and assist student learning of a variety of engineering concepts. The compact design is able to fit on a standard classroom tablet-arm desk, and costs of each LC-DLM are comparable to that of a textbook.

Although the LC-DLMs and have proven to work at a handful of initial test institutions, without the ability to easily translate to other universities, it would not be an ideal learning device for adoption. To optimize dissemination efforts, this project follows a hub-and-spoke model. Although the terms "dissemination" and "propagation" are commonly used interchangeably, they act as two separate steps that lead to the overarching goal of adoption: dissemination is the sharing of methods, while propagation is the success of such methods when used at outside universities [2]. Currently, a major focus for this project is propagation of our implementation techniques to ensure consistent, positive results as we have been observing in the past.

As part of the project, new implementers attend in-person training workshops and have access to helpful materials such as instructional videos and a FAQ page to ease adoption of the LC-DLMs. After attending the workshop, faculty receive a subset of the four primary LC-DLM cartridges (two fluid mechanics and two heat exchangers) to use in their classrooms. These modules were previously constructed by vacuum forming but have been reformatted to be constructed by injection molding. This reformatting was necessary to ease mass production, allow for more reliable assembly, and make them less fragile. Three of the modules are currently being manufactured for dissemination, with the fourth scheduled for start of production in summer 2020.

With the size of this project, a point of interest for the researchers is collection of mass amounts of data to study the effects of hands-on learning on student performance and motivation. Because data from this project will be analyzed from a holistic approach, it is crucial to record what was done in each class and what could be changed for future implementations. The following sections address three objectives the group sought to accomplish in the first year of the project, along with updates, data, and findings from the first set of implementations.

Objective 1: *Disseminate transport course-related low-cost desktop learning module (LC-DLM) pedagogy through US regional hubs*

Two hub workshops (Southeast and South Central Hubs) were scheduled to be held in September 2019 at Campbell University (September 6, 2019) and University of Central Oklahoma (UCO) (September 20, 2019). Due to Hurricane Dorian, the Southeast workshop was postponed, with attendees being given the option of a one-on-one meeting with a co-author from Campbell Univ., attending one of next year's Southern Hub workshops or this past year's South Central Hub workshop. A few attendees for the South Central Hub were also unable to attend that workshop due to Tropical Storm Imelda with flooding in the Houston area; similarly these faculty are being offering one-on-one training or the ability to attend a later workshop in fall 2020.

Attendees at the Central Hub workshop were the "spoke" participants from both Year 2 hubs, including, Anderson Univ. and Howard Univ. (from the Campbell hub), and the Univ. of Oklahoma, Oklahoma State Univ., the Univ. of Tulsa, Kansas State Univ., Wichita State Univ., Lamar Univ., and the Univ. of Texas Rio Grande Valley. In addition, we had a representative from Univ. of New Mexico attend the UCO workshop who originally was not a part of this grant effort but is now interested in implementing DLMs in the classroom. A total of ten faculty from chemical and mechanical engineering departments at primarily undergrad institutions, minority serving institutions, and R1 universities, were trained at the year 2 workshop held at UCO. Some of them served as representatives for those planning to implement the LC-DLMs, but who themselves were not able to attend.

At this workshop, the PI's and co-PIs gave presentations on the motivation behind this project, DLM design, instructional philosophy, and best implementation practices. In addition, attendees had the opportunity to use all four modules (venturi meter, hydraulic loss, double pipe heat exchanger, and shell and tube heat exchanger) in conjunction with suggested classroom worksheets.

A total of 14 separate implementations of DLMs occurred in Fall 2019 compared to three in Spring 2019, and we anticipate an expanded number to take place in Spring 2020. This includes hub coordinators who attended the original workshop in Spring 2019 and spoke participants who attended a workshop or alternative training in Fall 2019. Interestingly, several participants self-propagated this pedagogy by guest teaching and implementing DLMs in other classes, in addition to using DLMs in their own classroom.

To support faculty after the workshop, a project website provides information and support to those implementing LC-DLMs in the classroom. Critically, the website contains video tutorials for each LC-DLM, accompanying worksheets, password protected links for cognitive and motivational surveys, FAQs, contact information, and faculty forms for pre- and post-implementation. Faculty who watched and utilized the video tutorials found them to be especially helpful in their implementation. Supplementary phone and video chat support was also provided to faculty who requested it.

Objective 2: *Reformat and develop new LC-DLMs for testing and dissemination*

The four primary low-cost DLM cartridges that were previously constructed by vacuum forming have all been reformatted to be constructed by injection molding. This reformatting was necessary to ease mass production, to allow for more reliable assembly, and to make them less fragile. The reformatted design also makes them more attractive to companies interested in commercializing the LC-DLMs, which is one route being pursued for their sustainability after the completion of this project.

An additional change made to the upgraded DLM cartridges was the use of uniform ancillary equipment. All modules now use the same connectors, pumps, and stands, so participants do not need four completely unique kits to implement the four modules. This also eases the set-up and tear-down of the equipment in the classroom; in fact, students can set up the modules in a few minutes with minimal instruction. Much of this equipment (other than the injection-molded cartridges) is also off-the-shelf, so faculty can replace worn parts after the duration of this project.

Injection molds for the hydraulic-loss, venturi, double-pipe heat exchanger, and shell-and-tube heat exchanger cartridges have all been designed in CAD. The hydraulic-loss, venturi meter and double pipe heat exchanger molds have been built and the corresponding injection-molded parts produced. An efficient assembly procedure has been developed, such that the assembly of a cartridge and pump takes on average 15 minutes with an experienced undergraduate worker. As seen in Figure 1 the injection-molded cartridges retain the excellent visual clarity that was available with the vacuum-formed DLMs. They also retain similar performance specifications, such as a short time to reach steady state and low temperature differences from the feed reservoir to the inlet or from the outlet to exit reservoir, i.e. little heat loss at the entrance and exit points. Close to 150 units of the hydraulic loss and 250 units of the double pipe modules have been produced as of January 2020, which we estimate to be sufficient through year 4 of the project. The venturi modules are currently under construction and will be available to faculty in Spring 2020.

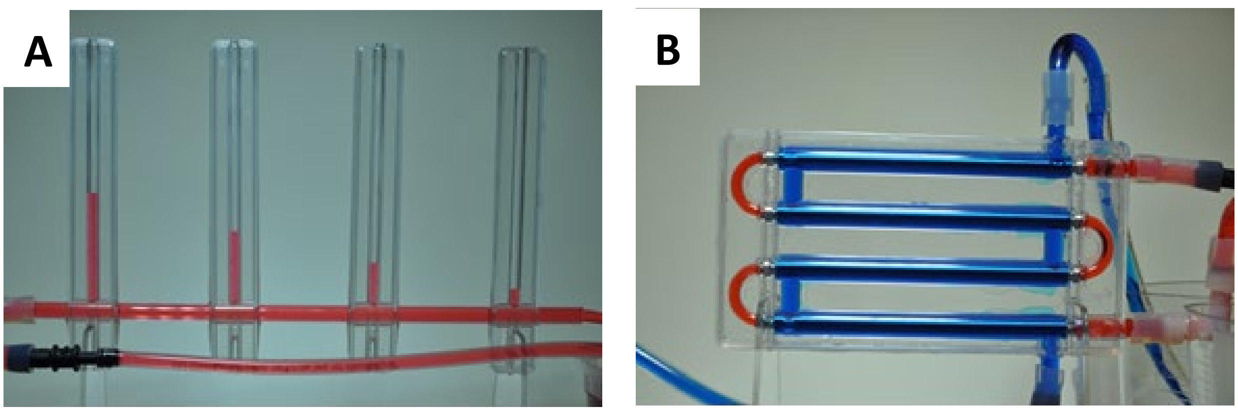

Figure 1: Reformatted injection-molded DLMs. A) Hydraulic-loss cartridge with water flowing from left to right showing frictional pressure loss. B) Double-pipe heat exchanger showing hot water (red) and cold water (blue) flowing through the system, hot on the tube side and cold on the annular side.

To accompany the updated DLMs, we also remade the accompanying worksheets based on feedback from hub coordinators [3]. We unified the learning objectives for both mechanical and chemical versions of the worksheets which align with the cognitive pre- and posttest questions. The instructions for DLM setup were streamlined and adjusted to fit with the new injection molded cartridges. All other questions were tied back to the stated learning objectives intended to force students to think about these concepts while using the DLM.

Objective 3: *Assess workshop and implementation effectiveness, and robustness of evidence surrounding improved learning and motivation associated with LC-DLMs across instructional settings*

While some version of these DLMs have been used for the past several years, student assessment has lacked robustness and thoroughness. To address this, we used Bloom's taxonomy to categorize learning outcomes, measure learning gains, and better analyze understanding of concepts embedded in use of exercises that involve the LC-DLMs. Questions were tested with a focus group of students in Spring 2019 [4] and a subset of those tested questions were used in the twelve different implementations in Fall 2019. A set of four-to-five questions were used in a pretest, taken before the DLM activity, and these same questions were used in a posttest, taken soon after the DLM activity, typically within 24 hours, but up to one week later. One to two additional questions were added to the posttest to account for the so-called “testing effect,” where students retain some amount of knowledge about the test questions [5]. Minor changes to some questions were made following the first semester of wide-spread use and these upgraded questions are being used in Spring 2020.

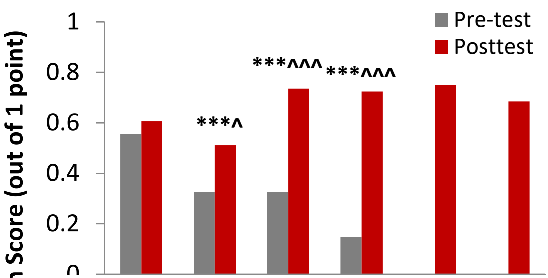

Figure 2: Overall pre- and posttest data for the hydraulic loss activity (n=210). Significant increases in the mean scores were seen for three questions (*** $p < 0.005$). Small effect sizes (^ $0.2 < d < 0.5$) were seen for the question regarding continuity and large effect sizes (^^^ $d > 0.8$) for velocity vs. distance and the paired explanation.

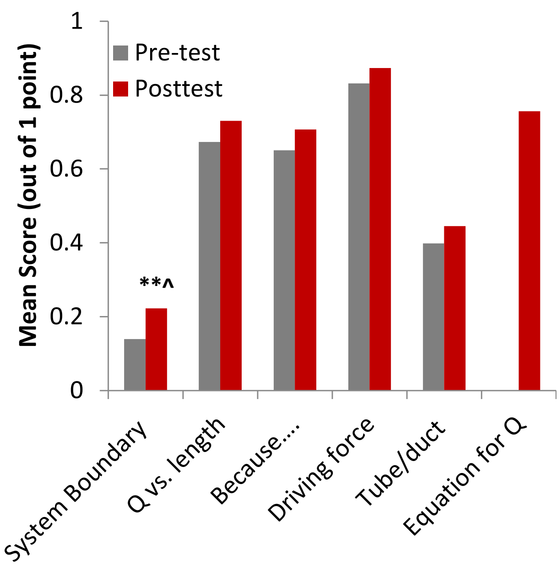

Figure 3: Overall pre- and posttest data for the double pipe heat exchanger activity (n=193). Significant increases in the mean score were seen for the system boundary question (** $p < 0.01$), as well as a small effect size (^ ($0.2 < d < 0.5$)).

A large number of students took the pre and posttests for the hydraulic loss and double pipe heat exchanger (because these were the injection molded modules available), and overall performances for this semester can be seen in Figures 2 and 3. We see significant improvement for three questions used in the hydraulic loss module pre and posttest (Figure 2), specifically about continuity and velocity trends, and see similar scores for the posttest only questions, which are related to conservation of energy. This leads us to hypothesize that students are gaining some increased understanding in concepts related to conservation through use of the DLMs.

Pre- and posttest data from the double pipe heat exchanger (Figure 3) implementation did not show as many significant improvements, indicating that there is a disconnect between what the students are gaining from the DLM and the questions we are asking. Current efforts are underway to address the cause of this disconnect and ways to improve the DLM implementation to help students achieve the stated learning objectives.

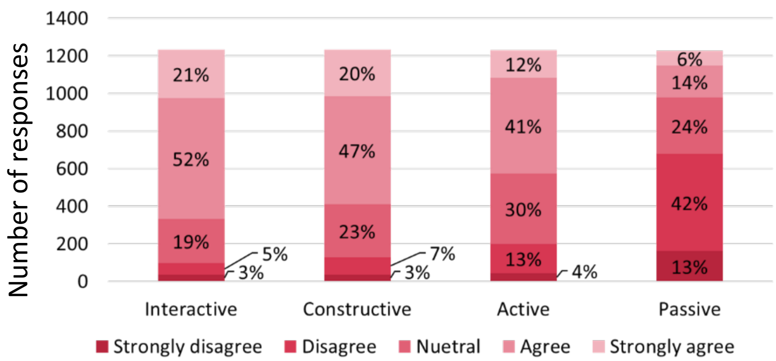

Figure 4: Student responses comparing interactions with the LC-DLMs to standard lectures.

In addition to cognitive tests, students are taking a motivational survey after completing the DLM activity to measure self-reported interest, value of activity, and level of engagement. We hypothesized that as students become more engaged with the DLMs, they will show a larger increase in their understanding of the concepts than someone who is disengaged. Preliminary data from Fall 2019 shown in Figure 4 indicates that students self-report more active engagement classified using the interactive, constructive, active, and passive (ICAP) framework when using the DLMs compared to lecture. This is consistent with trends observed by Chi et al. [6]. Additional analysis will be displayed at the ASEE poster session.

We also gathered formal feedback from faculty participants who attended the Central Hub workshop and implemented DLMs. We found that faculty had very positive feelings about the workshop (4 good and 6 excellent ratings, where excellent was the highest possible). They indicated that they gained knowledge about a number of different topics related to the project and felt that topical and engaging features were incorporated into the workshop. Critical feedback, including concerns about implementing DLMs in a fifty-minute class with students, will be addressed in future workshops. Information about their implementation will be used in conjunction with cognitive and motivational data to determine the effect of external factors, such as implementation style and institution type, on student performance.

Current and future outlook:

Based on pre- and posttest assessments as well as motivational surveys, the LC-DLMs continue to show positive results for conceptual learning and interactive gains, but now include implementations at other institutions. Questions and implementation worksheets will continue to be developed and modified based on concepts that the students continue to miss consistently even after use of LC-DLMs and based on feedback from faculty. Workshops will also be revised to address issues previous implementers have come across and enhance the implementation process for future users. We expect to design a study to compare how much results improved based on experience level in contrast to providing updated worksheets, activities and modified pre- and posttests. Although potentially time-consuming and requiring more effort, making the necessary modifications will ease propagation of the LC-DLMs, addressing one of our core values of accessibility of this learning tool.

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